Student Self-Regulation in Capstone Design Courses: A Case Study of Two Project Teams

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Abstract*—We studied two teams of senior engineering students in a mechanical and aerospace engineering capstone design course for four months to learn about their self-regulation strategies while immersed in an authentic classroom environment. The first team, which consisted of six students, were designing a patient lift system to be used by a semi-paralyzed lady in the local community. The second team, which consisted of five students, was working on a low-cost, motorized wheelchair for a client in India. Using a mixed methods approach, we collected data through nine different sources: Engineering Design Metacognitive Questionnaire (EDMQ), Canvas™ course webpage, an e-Journal, written interviews, participants' weekly presentations, journey maps, participants' cloud storage (Google Docs and Box), and participant-researcher-email communications. These digital data (i.e., voice, video, image, and text documents) are safely stored digitally in our secure network storage. This preliminary report addresses one major research question: In what ways do students actively employ self-regulated learning during design activities of a capstone senior design course. We drew upon Butler & Cartier's model of self-regulation and Dym & Little's design process frameworks to answer this question. The analysis used 48 e-Journal entries as its main source. We classified participants' entries by their design processes and activities; two engineering experts assisted in categorizing dubious records. Our data and interpretations were triangulated against other data sources during these processes to increase corroboration of our collected data. Our preliminary findings suggest that (1) groups' efforts were focused in conceptual design and project management activities, (2) groups' design processes were dynamics, and (3) management activities were reported throughout the project time. Further analysis will include other data sources, especially transcripts of students' weekly presentations, journey maps, and written interview responses, to uncover teams' self-regulation strategies during the design process.

***Keywords*—engineering design; self-regulation;**

I. Introduction

In engineering education, design is considered to be one of the core endeavors that helps students develop problem-solving skill, critical thinking, and creativity. In educational settings, as well as in the workplace, design is carried out in collaborative teams. ABET accreditation requires engineering programs to demonstrate that students are capable of functioning in teams [1]. Because design tasks encountered in team-based working situations are so ubiquitous, complex, and ill-structured; they offer substantial challenges to students and professional engineering designers. Student self-regulated learning, or self-regulation (SRL), has been found to play an important role in solving problems, particularly ill-defined problems, such as design tasks. A student uses self-regulation processes to oversee his or her learning process, plan and monitor ongoing cognitive activities and compare cognitive outcomes with internal or external standards [2]. The practice of SRL develops students' awareness of their thinking through metacognition. Having a better understanding of student SRL activities will help engineering educators to design and implement teaching interventions that promote student metacognitive awareness.

This article focuses only on students' self-regulation, which is defined as a complex repository of knowledge and skills for planning, implementing, monitoring, evaluating, and continually improving the learning process, in the contexts of design process and managing the design project. This is a work in progress, the third part of a three-phase research endeavor. The first phase was the development and validation of the Engineering Design Metacognitive Questionnaire (EDMQ) survey instrument (for further information see [3]); the second phase of the study was a quantitative study (breadth view), investigating a large number of students' self-regulation while solving their capstone engineering design projects using the validated EDMQ survey instrument. The intent of this part of the study is to enrich understanding about student's self-regulation of engineering design projects and collaborative, team management. It is expected that insight into student self-regulation activities will help engineering educators to design and implement teaching interventions that promote student metacognitive awareness.

II. Relevant Literature

A. Engineering Design

There are many models that describe the engineering design processes [4]–[6]; but despite their distinct differences, all models share similar design steps. Dym and Little [5] contend that the design process consists of five phases: problem definition (PD), conceptual design (CD), preliminary design (PYD), detailed design (DD), and design communication (DC). These design phases are considered as high-level overall views of design processes. They involve a sequence of actions or strategies that are self-contained cognitive approaches and relate to the current state of the design process. For example, during the problem definition phase, students analyze the design problem which may be divided into several functional subsets. Students frequently consider understanding of the problem to be the most important engineering design activity [7]. After clearly understanding the problem, they may be ready to propose a solution, analyze it, and decide whether to use it or find alternatives. Seniors found identifying constraints and iterating more important than did first-year students. This study will use Dym and Little's [5] five-stage prescriptive model to categorize and code cognitive engineering design strategies and evaluate students' metacognitive activities during the five design phases. This design model was selected because it offers specific cognitive strategies in each phase and clear coding categories for student cognitive strategies in engineering design.

B. Project Management

Teamwork goes beyond delegation of tasks, but also comprises efforts to balance power and responsibility among individuals as they seek to establish a working dynamic and ultimately control the path their team takes to accomplish its goal. Managing the time and resources students have at their disposal, as well as building and managing supportive relationships with teammates, necessitates that each member of the team continuously assess their own understanding of team, time and resource strategies and make necessary adjustments throughout the project. Numerous studies have suggested that group learning offers a basis for social comparison and social learning, [8] and that teamwork quality and team diversity impact the effectiveness and quality of task completion [9]. Project management (PM) in this work is comprised of three components: Team Management, Resources Management and Time Management.

C. Self-Regulated Learning

The influence of SRL in learning and problem solving has been demonstrated extensively [10]–[12]. A student uses good SRL skills to oversee his or her learning process, plan and monitor ongoing cognitive activities, and compare cognitive outcomes with internal or external standards [2]. Zimmerman and Pons [13] found that consistency in employing self-regulated learning strategies is highly correlated with student achievement. Schoenfeld [14] argued that an unsuccessful problem-solving effort may result from the absence of assessments and strategic decisions. Thus, students with poor self-regulation may benefit from training to improve self-regulation and subsequent learning performance [15].

The dynamic and iterative interplay between metacognitive and cognitive activity is described by Butler and Cartier [16]–[18] in the SRL model, which characterizes SRL as a complex, dynamic, and situated learning process [19]. This model involves six central features that interact with each other: (1) layers of context; (2) what individuals bring; (3) mediating variables; (4) task interpretation and personal objectives; (5) self-regulating strategies; and (6) cognitive strategies.

First, layers of context may include learning environments such as school, classroom, teachers, instructional approaches, curricula, and learning activities. In engineering design education, contexts include learning expectations in engineering as a field of study, the nature of engineering design tasks, and the expectations of particular instructors in different settings. Recognizing the ways in which multiple interlocking contexts shape and constrain the quality of student engagement in learning is essential for understanding SRL. The second feature is what individuals bring to the context (e.g., strengths, challenges, interests, and preferences). Over time, students accumulate a learning history that shapes the development of knowledge, skills, self-perceptions, attitudes toward school, and concepts about academic work [20]–[22]. Third, mediating variables include students' knowledge, perceptions about competence and control over learning, and perceptions about activities and tasks. Variables also include emotions experienced before, during, and after completing a task. The fourth feature is student task interpretation and personal objectives. Task interpretation is the heart of the SRL model insofar as it shapes key dynamic and recursive self-regulating processes. When confronted with academic work, students draw upon information available in the environment, and knowledge, concepts, and perceptions derived from prior learning experiences to interpret the demands of a task [17], [18]. Interpretation of task demands is a key determinant of the goals set while learning, strategies selected (i.e., the fifth feature) to achieve those goals, and the criteria used to self-assess and evaluate outcomes [17]–[19]. Students set personal objectives such as achieving task expectations to direct their engagement in learning. Sixth, students manage their engagement in academic work by using a variety of self-regulating strategies: planning, monitoring, evaluating, adjusting approaches to learning, and managing motivation and emotions. Students plan how to use available resources, select strategies for task completion, self-monitor progress, and adjust goals, plans, or strategies based upon self-perceptions of progress or feedback and performance. These strategies are iterative and dynamic endeavors.

This study focuses primarily on interpretation of the design task, self-regulating, and cognitive strategies of two teams working on their capstone engineering design projects. These variables called SRL features, sequence processes that might influence students' activities in completing an engineering design project. The richness of information arising from layers of context, what students bring to the design activity, and mediating variables are likely to be reflected in the way students interpret the design task and form personal goals. Task interpretation and personal objectives are expected to influence how students activate self-regulating and cognitive strategies during a design task and project management.

III. THE STUDY

This study was conducted within a mechanical and aerospace engineering capstone design course. This course was specifically designed to foster learning transfer; it provides a professional learning experience that represents the design process and project management similar to that expected in the engineering workplace. In order to be successful in this fourmonth course, students were expected to develop a design that met original design requirements and satisfies the customer.

A. Research Question

This research seeks to find an answer to one primary research question, which is "in what ways do students actively employ self-regulated learning strategies during design activities of a capstone senior design course?"

B. Research Participants and Design Projects

The research participants were two groups of students who enrolled in a Mechanical and Aerospace Engineering Capstone design course at a state university in the Intermountain West of the United States of America. Each group was self-formed and worked on a unique, fully funded engineering design problem. All participant-team-members were Caucasian, male students in their senior year. Students in both groups had a GPA between 3.00 and 3.74 on a 4-point scale.

The first group, which consisted of six students, was designing a patient bathroom lift (PBL) system to be used by a semi-paralyzed individual in the local community. The design objective was to develop a patient bathroom lift system that allows anyone with limited use of arms and legs the ability to independently use standard bathroom facilities, as found in a typical residence. In addition, the PBL project was intended for universal compatibility, such that equipment could be assembled, disassembled and adjusted at will, independent of location.

The second group, which consisted of five students, was working on a low-cost wheelchair (LWC) attachment to provide motorized assistance for clients in both the US and India. The power assist was to be compatible with a variety of manually operated wheelchairs in both countries. Similar to the first team, LWC had initial requirements such as being able to handle all-day use while remaining safe over steep gradients, surface discontinuities and varying terrain. Electronic controls such as a low-battery warning indicator should also be present in the final solution.

Students' self-regulation profile data were collected and analyzed through the EDMQ [23]–[25] instrument developed and validated during Phase 1 of this study. The instrument was developed through combining Butler and Cartier's self-regulated learning (SRL) model and features (i.e., task interpretation (TI), planning strategies (PS), strategic actions (SA), monitoring/fixed-up (MF), and criteria of success), as well as Dym and Little's 5-phase design process and project management components. Measurement scales of items for instruments ranged from 1 to 4 (i.e., 1 = almost never, 2 = sometimes, 3 = often, 4 = almost always). Averages of student's self-regulation level for design and project management in both teams are shown in Table 1.

C. Data Collection and Analysis

SRL is recursive, dynamic, multidirectional, and complex in nature [26], therefore relaying on large grain size data (e.g., aggregate or summative assessments) is not appropriate or beneficial in this type of research [19]. Qualitative data were collected through a Canvas™ course management webpage (e.g., groups' assignment submissions and grades), an e-Journal (eJ) [27], written interviews (seven questions about design and management), participants' weekly presentations (reports on design progress to instructor or, client, journey maps [28], participants' cloud storage (Google Docs and Box), and participant-researcher-email communications (e.g., workshop schedules or how-to).

The e-Journal was designed concordant with Dym and Little's 5-phase design process. Giving students the ability to concurrently design and report their activities online, can ensure the 'freshness' of data collected from the eJ. The eJ also enables the act of going back and forth at one's convenience to support the iterative nature of engineering design. A form with prompts (e.g., "How did you arrive at this result?") is available for the students to enter reports of their activities and upload related documents pertinent to each design phase. The reports also serve as a communication means among members in the team, or between the team and instructors, clients, or supervisors. Participants were asked to attach project deliverables, which amounted to design artifacts, later used to verify what was said. Approaching the end of the project time, participating students were asked to describe their cognitive (including metacognitive) actions and emotions while working on their design project graphically in a journey map. These sort of pictorial descriptions tell stories about student's design journey that cannot be captured by an eJ or survey instrument.

Participants' eJ entries were coded to identify SRL features and engineering design strategies. Two engineering-education experts assisted us in the coding process. The first and second experts have fifteen and seven years of experience working in academic and industrial settings, respectively. Both are currently enrolled in the doctoral degree of engineering education. Possible links between task interpretation, planning activities, and engineering design strategies will be made in order to identify accomplishments, adjustments, or the abandonment of strategies.

Coding of interview data will follow the main categories in the Butler and Cartier model. Specific attention will focus on how students describe task demands in all phases of the project. Common themes are expected that may facilitate knowledge about their understanding of design tasks, why they

TABLE I. STUDENT'S SELF-REGULATION LEVEL

		Bathroom Lift (PBL)		**Wheelchair (LWC)**	
		AVG	***SD***	***AVG***	***SD***
Design	***TI***	3.19	0.82	3.55	0.67
	PS	3.04	0.82	3.40	0.69
	SA	2.89	0.91	3.32	0.70
	MF	3.05	0.83	3.46	0.70
Project Management	***TI***	3.39	0.19	3.73	0.12
	PS	2.72	0.19	3.60	0.35
	SA	3.22	0.78	3.50	0.71
	MF	3.11	0.73	3.36	0.78

elect certain design strategies, how the strategies relate to task understanding, and how the strategies change during the course of a design project.

Narrative analysis [29] will be conducted to learn about participants' experiences in (1) an aspect of design, (2) team management, and (3) proposal development. This analysis will combine data from eJ (i.e., reported activities and system log), participants' weekly presentations (i.e., reported activities and plans), participants' cloud storage (i.e., design artifacts – final and draft version), journey maps (i.e., reported activities and challenges), written Interview (e.g., challenges), participant-researcher-email communications, and Canvas™ course Webpage (e.g., design communication documents). Data will be considered valid if it occurs in multiple sources. We can also claim validity of a data if associated design artifacts exist.

Phenomenological analysis [29] will be conducted to learn about (1) participant-expert co-regulation and (2) group monitoring and fix-up strategies. In this analysis we will use participants' weekly presentations (e.g., experts' feedback and group memos and meeting minutes), eJ (i.e., reported activities and plans), Canvas™ course Webpage (e.g., design communication documents and instructor's/client's feedbacks), written interview (i.e., reported monitoring/fix-up strategies), and participants' cloud storage (i.e., design artifacts – final and draft version).

IV. Preliminary Findings

Two rounds of coding approaches were employed: (1) based on design phases (e.g., problem definition or conceptual design) and project management; and (2) based on engineering design strategies (e.g., clarify design objective or identifying constraint) and project management components (e.g., time management). The experts coded 47 eJ entries (14 BL, 33 LWC) and 44 attachments (10 PBL, 34 LWC). The average Kappa score for PBL and LWC are 0.99 and 0.97 respectively, which can be interpreted as almost perfect agreement [30]. Preliminary findings of the first coding round are:

1) The two major experts' codes are problem definition-PD- (33.43%) and project management-PM- (21.37%) activities. These are followed by conceptual design-CD- (18.02%), preliminary design-PYD- (14.68%), detailed design-DD- (7.70%), and design communication-DC- (4.80%). This suggests group efforts were focused primarily on PD and PM activities.

2) Group design processes were dynamic, especially between neighboring design phases. In Fig. 1 and 2, the light-blue and orange dots appear simultaneously at the beginning of the project time, from the second to the eighth week. This suggests a dynamic transition between PD and CD, where the participants were trying to understand the problem and generate possible solutions. A similar pattern was also found between orange (CD) and grey (PYD) dots in the middle of the project time.

3) We found that 57 out of 91 eJ entries and attachments contain description of their management activities. A similar pattern was also found for DC (dark-blue dots). However, this occurred because the instructor required all students to present their design progress weekly. Fig. 1 and 2 show that both groups reported management activities throughout the project duration.

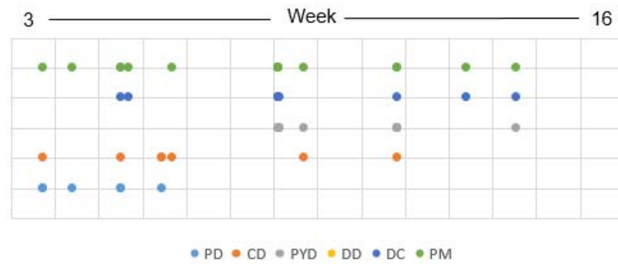

Fig. 1. Bathroom Lift group's chronological design process.

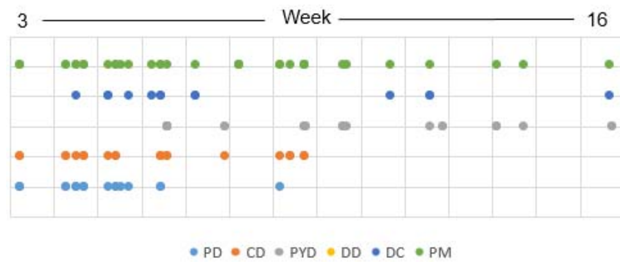

Fig. 2. Wheelchair group's chronological design process.

V. Next Step

Second round coding is in progress. Once it is done, we will continue with identifying student self-regulation activities (e.g., interpreting task, making plans, monitoring and fix-up, etc.). Further analyses by confirming, cross-validating, or corroborating findings within the study will be conducted. Particular efforts will be put into analyzing transcripts of students' weekly presentations, journey maps, and written interview responses, to uncover teams' self-regulation strategies during the design process. Based on the research results, a teaching guide and intervention will be developed to help educators in developing instructional materials that can help students to improve control over design engagement and performance.

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